REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
10-31-2011		From: 02-01-2008 To:08-31-2011

4. TITLE AND SUBTITLE

(DCT-FY08) MULTI-MODE, MULTI-ANTENNA SOFTWARE DEFINED RADAR FOR ADAPTIVE TRACKING AND IDENTIFICATION OF TARGETS IN URBAN ENVIRONMENTS

5a. CONTRACT NUMBER

5b. GRANT NUMBER
FA9550-08-1-0025

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Emre Ertin, Lee Potter, Joel Johnson

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Ohio State University Research Foundation
1960 Kenny Road
Columbus OH 43210-1016

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AirForce Office of Scientific Research
875 N. Randolph Street
Arlington VA 22203

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-OSR-VA-TR-2012-0703

12. DISTRIBUTION / AVAILABILITY STATEMENT

Public Release

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Under this research program we have developed vertically integrated software defined radar systems that can adapt to user sensing requirements in real-time. Multiple phase centers facilitate polarimetric and interferometric operation as well as serve as a testbed to implement and test multi-input, multi-output (MIMO) and waveform adaptive radar concepts. This research program made advances on three fronts: 1) Development of reference designs for next generation MIMO radar platforms. 2) New transmit waveform designs and adaptive waveform scheduling algorithms for improved detection and tracking. 3) Experimental and theoretical analysis of MIMO target signature

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**		14	**19b. TELEPHONE NUMBER** *(include area code)*

(DCT-FY08) MULTI-MODE, MULTI-ANTENNA SOFTWARE DEFINED RADAR FOR ADAPTIVE TRACKING AND IDENTIFICATION OF TARGETS IN URBAN ENVIRONMENTS

Final Technical Report for FA9550-08-1-0025

Principal Investigators: Emre Ertin, Lee C. Potter and Joel T. Johnson

1.INTRODUCTION

Under this research program we have developed vertically integrated software defined radar systems that can adapt to user sensing requirements in real-time. (www.ece.osu.edu/~ertine/RFtestbed) Adaptation of both transmit waveform and receive signal processing enables the radar to operate in *multiple modes* including Moving Target Indicator (MTI), High Range Resolution (HRR) MTI, Synthetic Aperture Radar (SAR) and Inverse Synthetic Aperture Radar (ISAR). Multiple phase centers facilitate polarimetric and interferometric operation as well as serve as a testbed to implement and test multi-input, multi-output (MIMO) and waveform adaptive radar concepts. Although many traditional multi-antenna radar concepts such as phased-array, receive beamforming, STAP, polarimetry and interferometry can be seen as special cases of MIMO radar, the distinct advantage of a multi-antenna radar system with independent transmit waveforms is the increased number of degrees of freedom leading to improved resolution, parameter estimation performance and reduced PRF and/or Transmit Power.

The operational principle of a software defined radar system is to sample the transmit/receive waveforms using high speed digital/analog and analog/digital converters and to implement key processing stages using programmable digital hardware. The block diagram for the proposed software defined radar system is given in Figure 1. A high speed digital waveform generator is used to construct independent waveforms for a set of transmit antennas, and produces a synchronized multi-channel baseband transmit signal which is mixed and amplified for transmission. In the receive signal chain, the received energy is filtered, amplified, and downconverted by an RF module, sampled in the baseband bandwidth synchronously across the multiple channels, and passed to an FPGA-based real-time signal processor for multi-channel coherent processing. The adaptive operation of the system is controlled by the information driven active sensing layer which allocates system resources to achieve ISR objectives by supplying the user with ATR primitives (target detections, target track, and ID).

This research program made advances on three fronts: 1) Development of reference designs for next generation MIMO radar platforms. 2) New transmit waveform designs and adaptive waveform scheduling algorithms for improved detection and tracking.
3) Experimental and theoretical analysis of MIMO target signatures. The main results are summarized in Sections 2 – 4. The research publications are given in the Section 5.

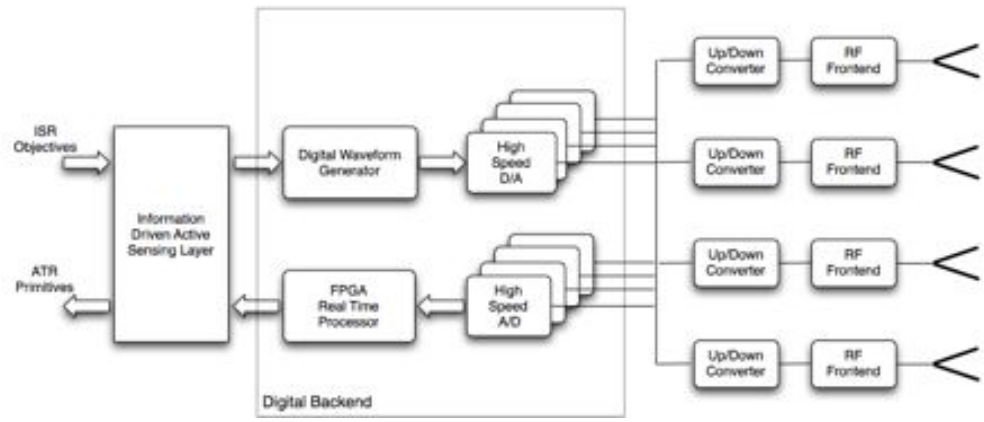


Figure 1: Multi-mode, Multi-channel Software Defined Radar

2. Development of reference designs for next generation MIMO radar platforms.

OSU prototype radar sensors combines high bandwidth digital back-end with a RF front-end having a variable center frequency over a wide frequency range (covering L, S, C, X, and Ku bands). For the AFOSR Discovery Challenge Thrust program, OSU developed three prototype software defined radar sensors that are fully functioning:

1) OSU Software Defined MicroRadar builds on the Texas Instrument small form factor software defined radio with a custom wider band RF Frontend for realtime range-doppler processing of 125 MHz instantaneous bandwidth at C band (5.4-6.4 GHz).

The MicroRadar consists of a TI DM6446 DSP, a Xilinx Virtex-4 SX35 FPGA, 2 digital to analog converters (DAC)s, and 2 ADCs. The ADCs sample at a rate of 125 mega samples per second (MSPS). The DACs are given data at a maximum rate of 125 MSPS; The DACs digitally upsamples and filters to a rate of 500 MSPS, mitigating frequency domain images when the full 125MHz of bandwidth are used.

2) OSU Ultrawideband MIMO Radar testbed provides upto 7.5 GHz UWB instantaneous RF bandwidth on 4 Transmit and 4 Receive Channels using Tektronix/Agilent Test Equipment, with a MIMO RF down and upconverters operating at 0.1-26 GHz. It allows flexible data collection campaigns with independent coherent waveforms for postprocessing.
The testbed uses two Tektronix AWG7122B dual channel 12GS/s Arbitrary Waveform Generators to generate coherent waveforms on four channels at 10 bit resolution. Two Agilent E8267D PSG vector signal generators with Wideband I/Q Modulators can upconvert to baseband waveforms to higher RF frequencies. These signals are fed to wideband antennas with LNA on transmit and receive. On receive side, four channel Agilent N5280A MIMO Downconverter (10MHz to 26.5 GHz) is used to downconvert

the received signals to baseband which is then sampled with four channel Tektronix DPO71254 12.5 GHZ Digital Oscilloscope with 50GSPS interlaced sampling rate and 8 bit resolution. An Agilent N5183A MXG analog microwave signal generator is used to generate carrier frequency references for the system.

3) OSU Software Defined MIMO Radar Sensor combines 4 transmit and 4 receive channels with FGPA/DSP for realtime MIMO radar processing with 500 MHz instantaneous bandwidth at 2-18 GHz. The digital backend uses 1 GSPS ADC (8 bit) and DAC (14 bits) boards from Sundance Multiprocessor Technology. The digitized signals are controlled through Xilinx Virtex-4 SX 35 FPGAs, higher layer signal processing tasks are handled through four TI C6416 32bit fixed points DSP’s per channel operating at 1 GHz.
For the MIMO radar sensor, OSU developed a wideband (2-18GHz) frequency RF frontend based on a standard superheterodyne design with two stages of mixing. The first LO is at a fixed frequency of 2GHz, enabling RF filter designs with sharp cutoffs. The second LO is tunable for mapping the operating frequency to the fixed frequency of the first LO stage. The second LO filter uses switchable filter bank on the low frequency band (2-6 GHz) and a bandpass yttrium iron garnet (YIG) filters on the high frequency band (6-18 GHz). Full polarimetric sensing is enabled by an integrated RF switching matrix. The antenna feeds have integrated low noise amplifiers (LNA) to account for cable losses in a MIMO array. OSU SDR effort also designed wideband antennas for SDR systems such as the low cost planar printed antenna that can operate in the 2-18 GHz band.

[For details: C. Rossler, E. Ertin and R. L. Moses, “A software defined radar system for joint communication and sensing,” in Radar Conference, 2011 IEEE, May 2011, pp 1050-1055.
M. Frankford, N. Majurec, and J. Johnson, “Software-defined radar for MIMO and adaptive waveform applications,” in Radar Conference, 2010 IEEE, May 2010, pp. 724 –728.]

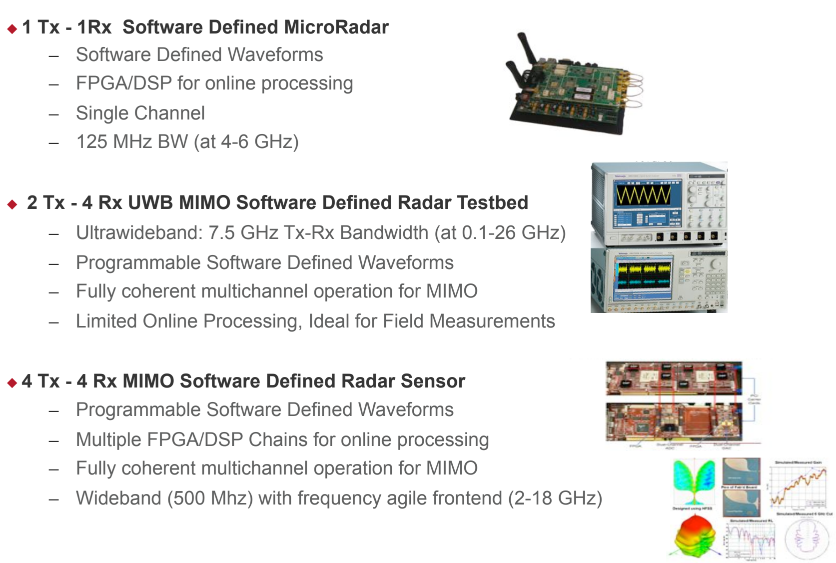


Figure 2: OSU Software Defined Radar Sensors

3. New transmit waveform designs and adaptive waveform scheduling algorithms for improved detection and tracking with software defined radar systems

Software defined radar systems developed under research thrust 1 result in systems that can adapt their transmit waveforms and receive processing according to the changes in environment and sensing objectives. Software defined radar platforms provide the flexibility to switch between different operation modes to detect, track and classify targets in the scene. As a result adaptive radar systems can operate in a closed-loop sensing mode, where current information of the target state is used to choose the next set of waveforms to maximally resolve target state uncertainty. This leads to improved performance and efficient use of radar resources such as bandwidth, duty- cycle, transmit power. Moreover multiple SDR platforms can coordinate their sensing actions to provide sensing in complementary dimensions of the target state resulting in further gains.

3.1 Waveform Scheduling for Collaborative Radar Networks

As part of this research thrust we focused on adaptive waveform scheduling for multiple Range-Doppler radars operating collaboratively for target tracking [Ghosh,Ertin, 2010]. In radar sensing, in order to get good range resolution, a signal with large bandwidth (and narrow in time) have to be transmitted. On the other hand to get good Doppler resolution the transmitted signal needs to extend in time so that it can detect the slow Doppler frequency shift caused by the moving target. This tradeoff between range and Doppler resolution performance is characterized by the Ambiguity function of the transmit waveform. The ambiguity function of the received waveform gives the estimation accuracy of the delay and Doppler of the targets. The Cramer-Rao lower bound (CRLB) on the error covariance can be obtained from the curvature of the peak of the ambiguity function at the origin of the delay-Doppler plane. Since CRLB gives local information, using CRLB at low-SNR environment results in poor performance. An alternative approach based on resolution cells has been proposed for this case. We considered high SNR case and used CRLB to characterize estimation accuracy.

There are two main approaches to waveform-agile target tracking in radar: the control theoretic approach and the information theoretic approach. In the control theoretic approach a waveform dependent cost function such as the mean-squared error is optimized to design the waveform to be transmitted in the next pulse. In the information theoretic approach, the mutual information between targets and the waveform dependent observations is maximized. In this article the information theoretic approach is adopted. Information theoretic methods for waveform-agile sensing include determining the optimal spectrum of the transmit waveform that maximizes the mutual information between target response and the measurement for detection, and selection of the optimal waveform from a fixed waveform library to maximize mutual information between the target state and measurement for tracking. Previously it was shown that for a single radar the waveform library can consist of only two chirp waveforms with chirp rates αmin and αmax, where αmin and αmax are minimum and maximum chirp rates supported by the radar hardware. We extended this result to multiple radars interrogating the same target. Our result shows that the radar platforms have to employ a mixture of minimum and maximum chirp- rates supported by the radar hardware to maximize mutual information between the target state and measurements. For the case of two identical radars we completely characterize the optimal combination of minimum and maximum chirp waveforms as a function of prior target state covariance, carrier frequency, width of transmitting pulse and allowable chirp rates. We further extended the result for arbitrary number of radars at arbitrary geometry.

[For details: A. Ghosh and E. Ertin, “Waveform agile sensing for tracking with collaborative radar networks,” Radar Conference, 2010 IEEE, pp. 1197 – 1202, 2010.]

3.2 Radar waveforms for joint communication and sensing

As part of this research thrust we considered software defined radar (SDR) systems operating jointly as a radar and communication system. The high bandwidth and throughput required by radar have resulted in traditional systems in which most functionality is built into the radar hardware; resulting in systems which can only be used for a specific application. SDRs, however, have much of their functionality built into software. This allows the SDR to, for example, change modes from synthetic aperture radar (SAR) imaging to moving target indication (MTI), or adapt its waveform based on environmental conditions and/or information derived from previous radar interrogations.

Previous research in this area focused on spread spectrum designs with code division multiple access (CDMA). Analog chirp filters were used to produce an up-chirp, which is used as a radar waveform, coupled with a down-chirp that is used as a spread spectrum communication signal; this approach results in low correlation between the radar and communication signals. A potential shortcoming of CDMA techniques is that the addition of two signals will result in a non-constant amplitude signal which will be distorted if a nonlinear amplifier is used. Another technique to accomplish joint functionality, which is considered in this work, is to directly use a wideband communication signal as the sensing waveform of the radar. We studied single-carrier digital communication waveforms under the performance criteria of a radar waveform. We also implement a self-adapting SDR which communicates, in real-time, the range profiles created by the radar portion of the joint system. In particular we studied the effectiveness of commonly used single-carrier digital communication schemes when used as radar sensing waveforms. Digital communication waveforms are designed to maximize spectral efficiency while minimizing; bit error rate, intersymbol interference, as well as the effects sampling clock/local oscillator mismatches. On the other hand, waveforms for radar sensing are evaluated based on a different set of criteria; maximizing detection performance, mitigating the effects of highly non-linear RF amplifiers, range-Doppler resolution, and sidelobe levels. We studied single-carrier digital communication waveforms under the performance criteria of a radar waveform. Regarding detection performance and non-linearity, we consider amplitude fluctuations and peak-to-average-power- ratio (PAPR) of three commonly used modulation schemes. In order to determine range resolution and peak-to-average- sidelobe-ratio (PSLR), we derive the autocorrelation function (ACF) for digital communication waveforms and show that the PSLR is constant under modest assumptions.

[For details: C. Rossler, E. Ertin and R. L. Moses, “A software defined radar system for joint communication and sensing,” in Radar Conference, 2011 IEEE, May 2011, pp 1050-1055.**]**

3.3 Compressive illumination waveforms for high resolution radar systems

Frequency Modulated Continuous Wave (FMCW) radars achieve high range resolution using frequency modulated waveforms with large time-bandwith products and match filtering on receive. For a linear FM waveform the match filter processing can be implemented through demodulating the received signal by mixing with the sweeping local oscillator and sampling the resulting lower bandwidth signal. The time samples from the analog-to-digital converter (ADC) provide a frequency spectrum which in return yields scene reflectivity as a function of range. The Nyquist sampling rate for the ADC is determined by the radar spot size and chirp rate which is typically less than the total bandwidth swept by the linear FM signal. Sub-Nyquist sampling in time has been avoided in practice since it creates potential ambiguities in range.

Recent results collectively known as compressive sensing has provided provable performance guarantees and signal recovery algorithms for random sub-sampling of sparse or compressible signals. Practical demonstrations of compressive sampling strategies focused on building receivers which rely on random projection and sub-sampling schemes exploiting sampling in frequency or spatial dimensions.

As part of this research thrust we proposed a novel compressive sensing strategy for radar that relies on on using compressive illumination with waveform designs across frequency, that shifts the burden of the sampling operator from the receiver to the transmitter. The proposed compressive illumination techniques require generation and sampling of multichannel coherent wideband waveforms. Aliasing after adaptive illumination reduces the sampling bandwidths at the expense of increased complexity in the transmitter structures. The concept of using low-resolution radar receivers at different frequencies is not new. For example, Gjessing considers use of multifrequency continuous wave radar system for high range resolution radar applications, Jankiraman employed multifrequency linear FM continuous wave radar system in the design of a wideband radar system. These systems use parallel radar processing chains operating simultaneously where transmit signals are combined through Wilkinson power combiner at the antenna feed and receive signals are resolved using parallel bank of band pass filters and fed into multiple stretch processors with a dedicated A/D per channel. This requires complex RF design for maintaining gain balance and phase coherency across the channels in transmit and receive, compensating for non-identical mixers and synchronization problems of stretch processors for each carrier. In addition the hard-ware complexity grows linearly with the number of carriers making hundreds carriers a practical impossibility. Our proposed technique will instead purposefully mix the different channels across the frequency, pulse and antenna array for maximizing the information rate of low-frequency A/Ds. As an example for a multiple carrier signal all the received signals from the multiple carriers are aliased onto the narrowband receiver of a single carrier requiring only a slower A/D. The design complexity is not dependent on the transmitted waveforms (e.g. the number of carriers).

We presented theoretical analysis of the compressive illumination strategy through characterization of the coherency of the resulting sampling dictionary and relation between bandwidth, sampling rate and scene sparsity.

We generated multi-frequency linear FM signals with 750 MHz total bandwidth and 10 microsecond duration, composed of 15 subcarriers each with 50 Mhz bandwidth with non-overlapping frequency support . The center frequencies and complex phases of the subcarriers are randomly selected at each simulation run. The wideband received waveform is then dechirped using a single stretch processor with a single reference chirp of 50 MHz bandwidth and sampled at a rate of 5 Msample/sec of complex I/Q samples corresponding to an unambiguous range of 150 meters. As a result the multifrequency returns are aliased with random circular shift and complex amplitude and added on to the reference dechirp sequence. Figure 3 shows the results for the case of 10 point targets with traditional radar sensor and compressive illumination with 15 subcarriers. We observe that for a traditional single carrier chirp system, the system output is readily interpretable as the range profile with resolution matching the 50 MHz bandwidth. Basis pursuit recovery algorithm using the prior knowledge of SNR for the single carrier chirp results in localization of most targets, however closely spaced targets cannot be detected with few false detections. For the multiple carrier chirp transmit waveform the radar receiver output is harder to interpret visually since each of the 10 targets is aliased 15 times. However Basis pursuit recovery algorithm armed with the knowledge of the aliasing pattern can reliably detect all 10 targets.

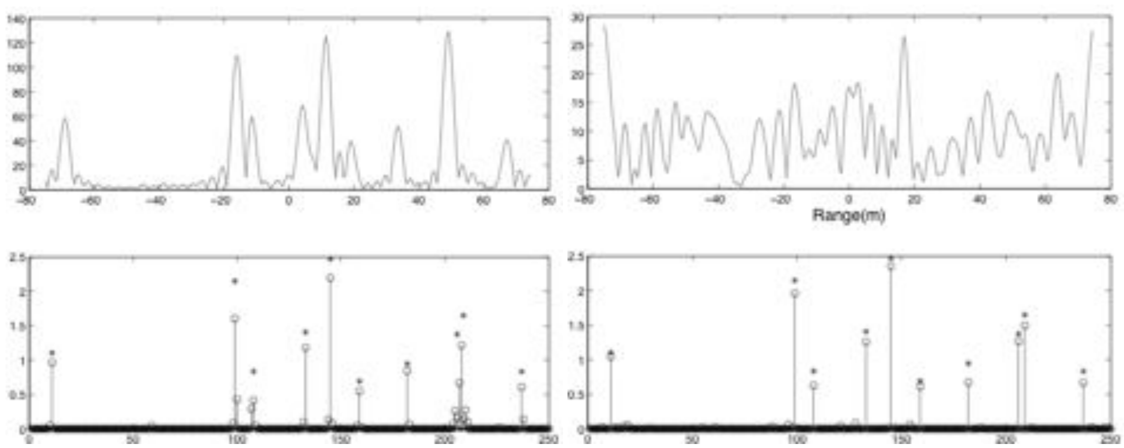


Figure 3. (Left) Received signal for a traditional single carrier transmit LFM waveform and dechirp receiver and corresponding sparse recovery of target response using BP. (Right) Received signal for a compressive illumination waweform with 15 subcarrier LFM waveform and dechirp receiver and corresponding sparse recovery of target response using BP. In each case "*" shows the true target locations and amplitudes, "o" shows the detected target locations and amplitudes. We observe that unlike the traditional radar sensor, the compressive illumination sensor can reliably detect all 10 targets.

[For details: E. Ertin, L. C. Potter and R. L. Moses, "Sparse Target Recovery Performance of Multi-frequency Chirp Waveforms," Proceedings of the 9th European Signal Processing Conference (EUSIPCO 2011) , June 2011
E. Ertin, "Frequency Diverse Waveforms for Compressive Radar Sensing," Fifth International Waveform Diversity and Design Conference (WDD 2010), Niagara Falls, Canada, August 2010.]

4. Experimental and theoretical analysis of MIMO target signatures.

Multiple-input multiple-output (MIMO) radars with spatially diverse transmitters and receivers have the potential to provide target detection improvements as compared to their phased array counterparts by providing better measurements immunity to fading in a target's radar cross section (RCS) as aspect angle is varied. Previous works have performed target detection studies using Swerling target RCS models extended to the multi-static case. Using such a model, Fishler et. al. showed the optimal detector for a MIMO radar system to be a simple energy detector (i.e. an incoherent combination of received powers from all transmit- receive pairs). The target model used in this studies was a finite rectangular area uniformly filled with an infinite number of scatterers (similar to a Swerling-I model) whose complex scattering amplitudes were independent and identically distributed (IID) random variables. Under this assumption, it was shown that the target detection performance of the MIMO radar system considerably exceeded that of its phased array counterpart at higher signal-to-noise ratios (SNR). The applicability of these conclusions has remained uncertain because the statistical model used may not completely represent the multi-static scattering behaviors found in realistic targets.

To address this issue, a unique "experimental" study is conducted ; this was based on the use of a software-defined radar (SDR) developed under the AFOSR DCT program with M = 2 transmit elements and N = 4 receive elements and measured the 2.75 and 4.5 GHz scattered fields of a small UAV target.

The radar system was operated in an anechoic chamber and used two transmit and four receive vertically- polarized antenna assemblies in a spatially diverse array (co- ordinates and elevation angle are plotted in Figure 4.) Photographs of the antenna assemblies directed toward the UAV (mounted on a low RCS azimuthal rotator system) are also included in Figure 4. While the wing structures of the UAV are mostly lightweight wood and plastic, the fuselage is packed tightly with electronics, a camera on gimbals, antennas, a fuel tank, and an engine, providing a set of complex scattering centers. The SDR system consisted of two independent transmit channels and two independent receive channels with an in- stantaneous bandwidth of 500 MHz. In addition, the SDR contained an RF switch matrix connecting the two receive channels to any of four dual-polarized receive antennas. Using these capabilities, the SDR was configured to measure the scattered fields for all MN = 8 combinations of vertically polarized elements at two center frequencies: 2.75 GHz and 4.51 GHz.

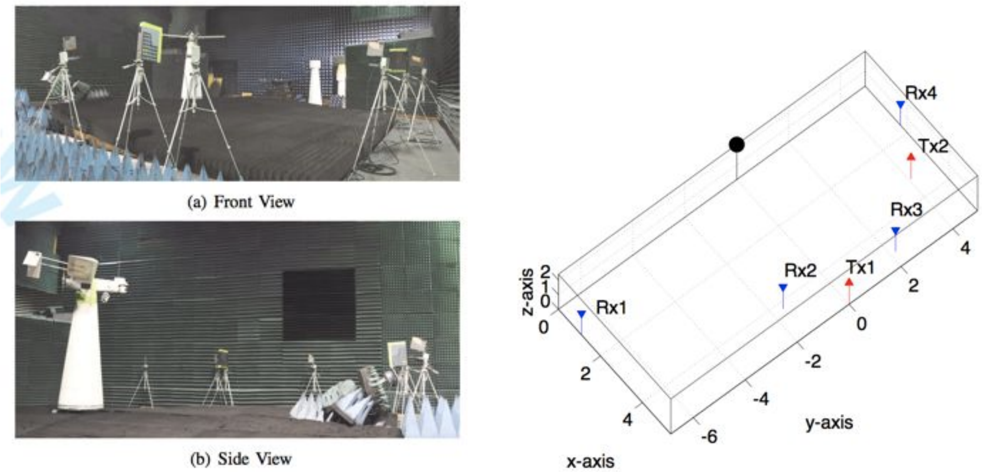
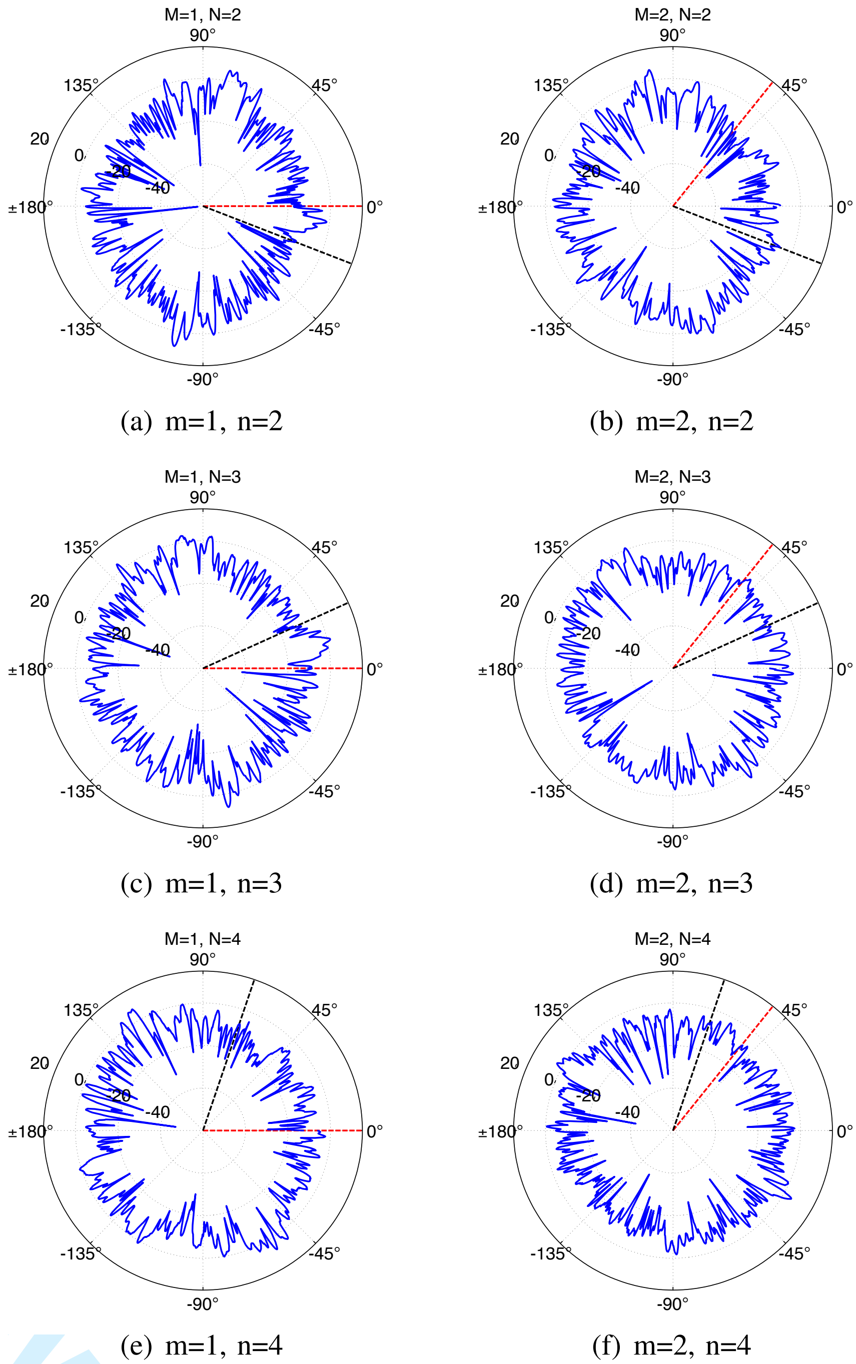


Figure 4. (a-b) Photographs of the UAV mounted on the foam column with spatially diverse SDR transmit and receive antenna assemblies. (c) Locations in meters of transmit and receive elements with respect to the target. Black dot represents target location.

The downrange resolution of the 500 MHz LFM chirp waveforms following pulse compression was approximately 1/3 m. Therefore, the UAV's 2 m fuselage could occupy up to six range bins depending on the UAV aspect angle. Because the MIMO detection process considers only a single range bin, and because it was desired to observe a complex target consisting of many scatterers, the measured data range resolution was reduced in post processing. To perform this reduction, first a time-domain window of length 7 samples (~2.7 m) was applied, effectively bracketing the target location to gate out any returns not directly attributable to the target. Fourier transform of this time-gated target response was then performed to obtain the response resolved in frequency. For every azimuth angle measurement a, the frequency point in the Fourier domain corresponding to the center frequency of the measurement was recorded; this represents a narrowband complex target response. In performing this procedure it was found that the direct path could not be sufficiently removed by time-gating the target return for pairs of elements having large bistatic angles. Therefore, only the responses measured by receivers n =2, 3, and 4 will shown in the following limiting the system to M =2, N =3.
The measured RCS levels in dBsm are illustrated in Figure 5 for the 4.51 GHz center frequency . Although the total variation of the RCS is limited by the dynamic range of the SDR to approximately 37 dB at most, significant variations in the RCS with target aspect angle are observed. Average RCS values for the 6 transmit/receive pairs vary from -7.8 to -5 dBsm at 4.51 GHz.



(a) m=1, n=2 (b) m=2, n=2

(c) m=1, n=3 (d) m=2, n=3

(e) m=1, n=4 (f) m=2, n=4

Figure 5. Measured MIMO RCS levels for the UAV target at 4.51 GHz center frequency as the target as rotated over 360 degrees

Using Monte Carlo simulations utilizing the measured data from different realizations, probability of miss detection was calculated for a false alarm rate of 0.01% utilizing the scattered field measurements both for MIMO radar and phased array (m = 2, n = 4 only) configurations. The resulting curves for 4.51 GHz center frequency is shown in Figure 6. For both center frequencies, MIMO radar results using the measured fields ("directly calculated MIMO") agree reasonably well with those of the statistical target model ("uncorrelated target") and again show enhanced detection performance for the MIMO configuration as compared to the corresponding phased-array once a sufficient SNR has been reached. Results for the phased array case are also similar between the measured data ("directly calculated phased array") and statistical predictions ("closed form phased array").

The results of these studies confirm for a realistic target that target detection performance can be enhanced at high SNR values through the use of spatially diverse MIMO radar as compared to the corresponding phased array system.

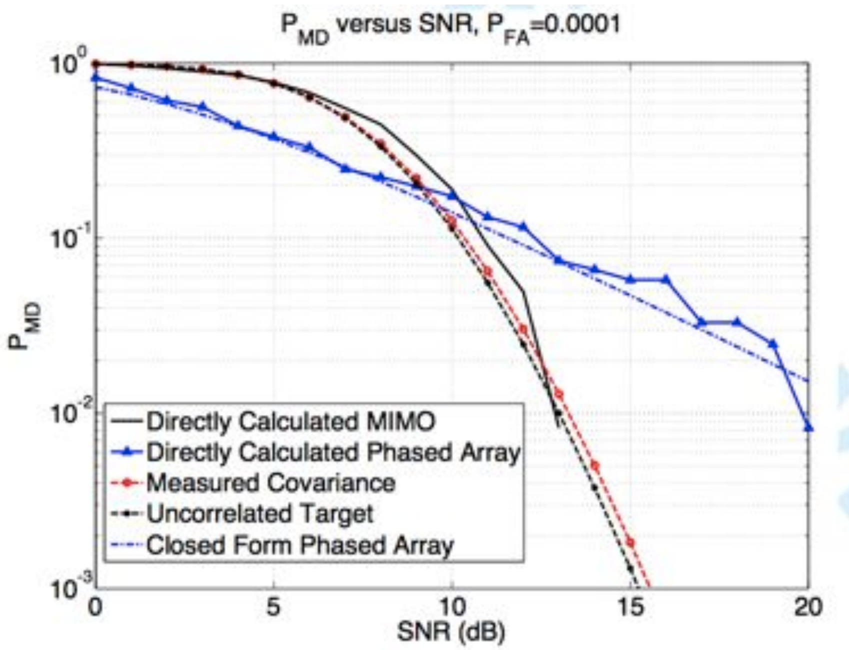


Figure 6. Probability of missed detection versus SNR for 0.01% false alarm rate for 4.51 Ghz center frequency. The Directly Calculated MIMO and Directly Calculated Phased Array curves are calculated through Monte Carlo simulations using the measured data, while the Measured Covariance curve is found through diagonalization of the covariance matrix estimated from the measured scattered fields. The uncorrelated target and closed form phased array curves present the results of the theoretical models used in literature.

[For details: K. Stewart, M. Frankford, J. Johnson, N. Majurec, and E. Ertin, "MIMO Target Measurements," in Proceedings of the 45th Asilomar Conference on Signals, Systems and Computers, 2011 (ACSSC11). Nov 2011.

M. T. Frankford, J.T. Johnson and E. Ertin, "Including Spatial Correlations in the Statistical MIMO Radar Target Model," IEEE Signal Processing Letters, vol. 17, no.8, April 2010]

5. Publications supported by the grant FA9550-08-1-0025

THESES and DISSERTATIONS

A. Ghosh, "Optimum waveform scheduling with Software Defined Radar for Tracking Applications," MS Thesis June 2010

M. Frankford, "Exploration of MIMO Radar Techniques with a Software Defined Radar," PH.D Dissertation June 2011

JOURNAL PUBLICATIONS

1. C. Austin, E. Ertin and R. L. Moses, "Sparse Signal Methods for 3-D Radar Imaging," IEEE Journal of Selected Topics in Signal Processing, vol.5, no.3, June 2011

2. E. Ertin, R. L. Moses and L. C. Potter, "Interferometric Methods for 3-D Target Reconstruction with Multi-Pass Circular SAR." IET Journal on Radar, Sonar and Navigation, vol.4, no.3, June 2010.

3. L. C. Potter, E. Ertin, J. Parker, M. Cetin, "Sparsity and Compressed Sensing in Radar Imaging," IEEE Proceedings, vol.98, no.6, Feb 2010

4. M. T. Frankford, J.T. Johnson and E. Ertin, "Including Spatial Correlations in the Statistical MIMO Radar Target Model," IEEE Signal Processing Letters, vol. 17, no.8, April 2010

CONFERENCE PUBLICATIONS

1. K. Stewart, M. Frankford, J. Johnson, N. Majurec, and E. Ertin, "MIMO Target Measurements," in Proceedings of the 45th Asilomar Conference on Signals, Systems and Computers, 2011 (ACSSC11). Nov 2011.

2. E. Ertin, L. C. Potter and R. L. Moses, "Sparse Target Recovery Performance of Multi-frequency Chirp Waveforms," Proceedings of the 9th European Signal Processing Conference (EUSIPCO 2011) , June 2011.

3. C. Rossler, E. Ertin and R. L. Moses, "A software defined radar system for joint communication and sensing," in Radar Conference, 2011 IEEE, , pp 1050-1055. Kansas City, May 2011

4. E. Ertin, “Frequency Diverse Waveforms for Compressive Radar Sensing,” Fifth International Waveform Diversity and Design Conference, Niagara Falls, Canada, August 2010.

5. M. Frankford, N. Majurec, and J. Johnson, “Software-defined radar for MIMO and adaptive waveform applications,” in Radar Conference, 2010 IEEE, May 2010, pp. 724 –728.

6. A. Ghosh and E. Ertin, “Waveform agile sensing for tracking with collaborative radar networks,” Radar Conference, 2010 IEEE, pp. 1197 – 1202, 2010.

7. C. Austin, E. Ertin and R. L. Moses, “Sparse multipass 3D SAR imaging: applications to the GOTCHA data set”, Proceedings of SPIE 7337, E. G. Zelnio and F. D. Garber, Eds., March 2009

8. E. Ertin , R. L. Moses, and L. C. Potter, “Interferometric Methods for 3-D Target Reconstruction with Multi-Pass Circular SAR,” 7th European Conference on Synthetic Aperture Radar (EUSAR 2008), Friedrichshafen, Germany, June 2008